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Fertilizers for Early Cabbage, Tomatoes, Cucumbers, and Sweet Corn

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FERTILIZERS FOR EARLY CABBAGE, TOMATOES, CUCUMBERS, AND SWEET CORN

THIRD REPORT

JOHN BUSHNELL[1]

INTRODUCTION

For 26 years, a fertilizer experiment with early cabbage, tomatoes, cucumbers, and sweet corn has been in progress at the Washington County Truck Crops Experiment Farm, located near Marietta, Ohio, in a district where early vegetables are grown intensively.

The primary aim of this experiment has been to aid the growers in their fertilizer practices.

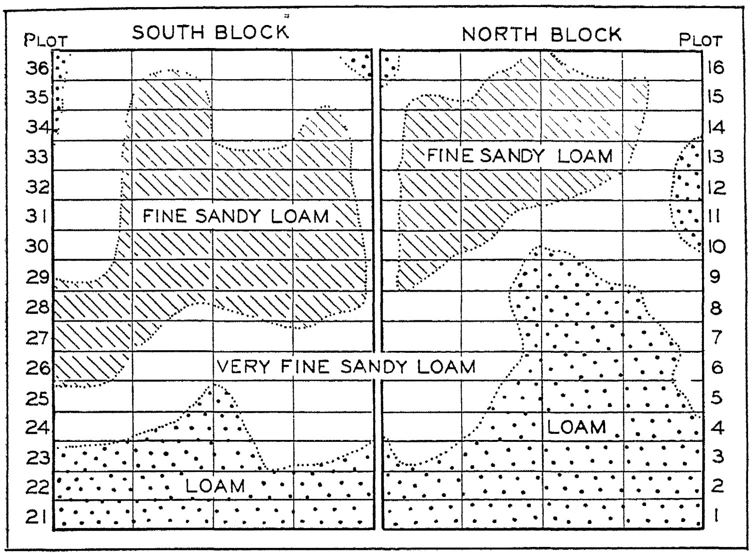

Fig. 1.—Soil map of the experimental area

Previous reports.—This experiment was originally planned by W. J. Green, then horticulturist at the Ohio Agricultural Experiment Station. Progress reports of the first 4 years were published in Ohio Agricultural Experiment Station Bulletins 303, 324, and 361. After the retirement of Green in 1921, the project was continued under the direction of J. H. Gourley and his associates. The results of the first 12 years were published in 1924 in Bulletin 377. Four years later, the data were again summarized in Bulletin 420. The present report deals principally with the data of the 8 years, 1931-1938.

[1]Throughout the entire 26 years of this experiment, the details of operation have been under the able supervision of O. N. Riley, foreman, who has taken all the records of yields. It is a pleasure to acknowledge his splendid work.

TABLE 1.—Annual application of manure and fertilizer constituents per acre

Plot*	First 8 years, 1915-1922				Lime†	Second 8 years, 1923-1930				Third 8 years, 1931-1938			
	Manure Tons	Nitrogen Lb.	Phosphoric acid Lb.	Potash Lb.	Tons	Manure Tons	Nitrogen Lb.	Phosphoric acid Lb.	Potash Lb.	Manure Tons	Nitrogen‡ Lb.	Phosphoric acid Lb.	Potash Lb.
North block													
1 ck	....	....	....	....	1	....	....	....	....	....	160	120	80
2	16	....	64	....	1	16	....	128	....	8	....	80	....
3	16	....	....	....	1	16	....	....	....	8	160	80	....
4 ck	....	....	....	....	1	....	....	....	....	....	160	120	80
5	16	....	....	....	1	20	....	....	....	16	200	80	....
6	....	50	128	50	1	....	50	128	50	....	240	180	120
7 ck	....	....	....	....	1	....	....	....	....	....	160	120	80
8	....	25	64	25	1	....	75	192	75	....	160	120	240
9	....	25	64	....	1	....	50	128	....	....	160	120	160
10 ck	....	....	....	....	1	....	....	....	....	....	160	120	80
11	....	....	64	....	1	....	....	128	....	....	160	120	....
12	....	25	....	....	1	....	75	....	....	....	200	120	80
13 ck	....	....	....	....	1	....	....	....	....	....	160	120	80
14	....	25	....	....	1	....	75	....	....	....	120	120	80
15	....	25	....	....	1	....	75	....	....	....	80	120	80
16 ck	....	....	....	....	1	....	....	....	....	....	160	120	80

TABLE 1.—Annual application of manure and fertilizer constituents per acre—continued

Plot*	First 8 years, 1915-1922				Lime†	Second 8 years, 1923-1930				Third 8 years, 1931-1938			
	Manure	Nitrogen	Phosphoric acid	Potash		Manure	Nitrogen	Phosphoric acid	Potash	Manure	Nitrogen‡	Phosphoric acid	Potash
	Tons	Lb.	Lb.	Lb.	Tons	Tons	Lb.	Lb.	Lb.	Tons	Lb.	Lb.	Lb.
						South block							
21	....	....	....	....	1	8	50	128	50	8	80	80	160
22 ck	....	....	....	....	....	....	....	....	....	....	160	120	80
23	16	25	64	25	....	16	25	64	25	8	80	240	....
24	16	....	....	....	....	16	....	....	....	8	80	160	....
25	16	....	....	....	1	16	....	....	....	8	80	....	....
26	16	25	64	....	1	16	25	64	....	8	80	80	....
27	16	....	....	....	....	16	....	....	....	16	....	....	....
28	16	....	64	....	1	16	....	64	....	16	80	60	40
29 ck	....	....	....	....	....	....	....	....	....	....	160	120	80
30	....	25	64	25	....	....	25	64	25	....	40	60	40
31	....	25	64	25	1	....	25	64	25	....	160	....	80
32 ck	....	....	....	....	....	....	....	....	....	....	160	120	80
33	....	....	....	....	1	....	....	....	....	....	....	....	....
34	....	25	64	....	1	....	25	64	....	....	160	200	80
35 ck	....	....	....	....	....	....	....	....	....	....	160	120	80
36	....	....	64	....	1	....	....	64	....	....	....	120	80

*"ck" indicates uniformly treated check plots.
†Ground limestone applied during first and second 8-year periods.
‡Applications of sulfate of ammonia in excess of 80 pounds of nitrogen per acre were applied as side dressings, except on plot 6, where the initial application was 120 pounds of nitrogen.

Type of soil and plot arrangement.—The experiment is located on terrace soil of the Muskingum River. As shown in figure 1, prepared by G. W. Conrey and A. H. Paschall of the Soil Survey Division, the soil varies from Chenango loam to fine sandy loam.

The field is level except for a gentle slope rising from plot 21 to plot 29 and declining toward plot 36. The soil has good natural drainage. There is no evidence of surface erosion on these slopes, but after a heavy rain, plots 21 and 36 have been observed to be somewhat slower to dry on the surface than the plots lying higher.

The plot arrangement is also indicated on the map. The fertilizers are applied to long, narrow plots, 224 feet long and 20 feet wide, each approximately one-tenth acre. The four crops are then planted across the plots, giving one-fortieth - acre plots of each crop on each fertilizer plot. With two blocks, or tiers, of 16 fertilizer treatments, and four crops, the total is 128 plots on which yield records are taken each year. Although not shown on the map, there is a 4-foot border strip between plots.

Varieties and rotation of crops.—The varieties are those commonly grown in the district. In recent years they have been as follows:

Tomatoes:	Bonny Best until 1935, Rutgers in 1936 and since
Cabbage:	Golden Acre
Cucumbers:	Early Fortune
Sweet corn:	Vanguard

The crops are grown every year in the following rotation: tomatoes, cabbage, cucumbers, sweet corn. The cultural methods are the same as those currently used in the district. The crop residues, except the corn stover, which is removed, are disked in. Soybeans are planted after the cabbage, and at the last cultivation of the tomatoes and corn. The soybeans are disked down in late September, when a winter cover crop is seeded. As the cucumbers occupy the land longer than the other crops, the winter cover crop is sown directly after the vines are disked. Until 1937, rye was used as the winter cover crop, but since that year, winter barley, which was found to be superior to rye, has been used.

FERTILIZER TREATMENTS

As shown in table 1, during the first 8 years all the manure applications were at the rate of 16 tons per acre, and the fertilizer applications were comparatively light. The basic application of 25 pounds of nitrogen, 64 pounds of phosphoric acid, and 25 pounds of potash was approximately equivalent to 625 pounds per acre of 4-10-4.

During the second 8-year period, most of the fertilizer applications were doubled on the north block.

At the beginning of the third 8 years, the plan was largely revised, principally to test the effect of much larger applications of fertilizers, particularly much larger amounts of nitrogen. Also at this time fertilizing the previously unfertilized check plots was started. Largely because manure was becoming scarce in the district, most of the manure applications were reduced to 8 tons per acre; only three plots were retained with 16-ton applications. The lime comparisons were discontinued, and the previously unlimed plots were given 8 tons per acre of ground limestone early in 1931.

Fertilizer materials.—Throughout the experiment, the fertilizers have been made by mixing superphosphate, muriate of potash, and nitrate of soda or sulfate of ammonia. Since 1931, sulfate of ammonia has been used as the only source of nitrogen, both in the mixtures and for the side dressings. The manure has been from the team of horses kept on the farm. It has been applied in the fall or early winter. The fertilizers for cabbage have been broadcast at the time of fitting the soil, about the first of April. For the other crops, the fertilizer has been broadcast and disked in about May 1. The side dressings have been applied at the times suitable to the individual crops.

CALCULATION OF YIELDS AND THE EXPERIMENTAL ERROR

For simplicity, all the yields reported are in weights of the harvested crops converted to pounds per acre. They are not true total yields, for they include, in most cases, only the marketable produce harvested during the period that the crops are sold in the district.

The Experiment Farm is not equipped with irrigation. Consequently, in drouth seasons, all the crops suffered reduction in yield. In 1930, the drouth was so serious that the records for the entire season were discarded. Since then, the only complete crop failure was sweet corn in 1936.

Use of check plots.—Every third plot in the north block (plots 1 to 16) and four plots in the south block were unfertilized for 16 years, then uniformly fertilized with 1,000 pounds per acre of 8-12-8 each year. The yields of all other plots are compared with these check plots to show the increase or decrease due to the difference in fertilizer treatment. This method of comparison eliminates some of the variation in yield due to variation in the soil. In calculating the increases or decreases it was assumed that the soil varied progressively from one check plot to the next. Thus, if check plots 1 and 4 yielded 500 and 530 pounds, respectively, it was assumed that plots 2 and 3 would have yielded 510 and 520 pounds, respectively, if they had had the same treatment as the checks. The actual yields of plots 2 and 3 were then compared with these intermediate check values.

Methods of estimating the significance of the increases in yield.—As the treatments are not replicated, accurate statistical analysis of the experimental errors cannot be made. To get a rough estimate of the variability of the yield due to the variations in soil and cultural conditions, the standard error of the checks on the north block has been calculated from their average yields for the 8 years they have been fertilized, 1931-1938 (table 2).

TABLE 2.—Estimate of the difference in yield between two plots required for statistical significance

Calculated from the variation in yield of the six check plots in north block, 1931-1938 (data of table 7)

	Generalized standard error of the 8-year average yield of any one check plot Lb. per acre	Standard error of the difference of two plots, assuming they both have same variability as checks Lb. per acre	Difference necessary to be on threshold of significance (odds about 19 to 1) Lb. per acre
Tomatoes	359	508	1,016
Sweet corn	594	840	1,680
Cabbage	728	1,030	2,060
Cucumbers	928	1,327	2,654

A method of calculating the statistical significance which is particularly applicable to adjacent plots is a comparison of the annual yields by a pairing method. When there was some doubt as to the significance of the difference in the yield of adjacent plots, Student's pairing method was used. As would be expected in comparing adjacent plots, some differences have proved significant when they were smaller than the estimates in table 2.

RESULTS OF THE FIRST SIXTEEN YEARS

Soil fertility at outset.—When the farm was acquired in 1915, the soil was reputed to be in a low state of fertility in comparison with that of neighboring farms. Samples of the soil were not taken at that time. In order to get an estimate of the original fertility of the soil, samples were taken in 1938 from the unfertilized and uncropped roadway surrounding the fertilizer block. Quick soil tests showed the following:

Acidity: pH 5.0 to 5.4
Available phosphorus, by Truog's (6) method: 50 to 75 pounds per acre (2,000,000 pounds of soil)
Replaceable potassium, by Thornton's (5) method: 100 to 200 pounds per acre

TABLE 3.—Average annual yield, first 8 years, 1915-1922

Plot	Annual application per acre				Average yield per acre			
	Manure	Fertilizer		Limestone	Tomatoes	Cabbage	Cucumbers	Sweet corn
	Tons	Amount Lb.	Formula*	Tons	Lb.	Lb.	Lb.	Lb.
1 ck.	...	...	...	1	10,188	15,905	15,346	7,520
2	16	400	0-16-0	1	14,485	20,907	19,340	7,960
3	16	...	...	1	13,803	20,005	18,567	7,960
4 ck.	...	...	...	1	10,343	16,225	15,225	7,425
5	16	...	...	1	13,255	19,400	19,549	8,290
6	...	1,250	4-10-4	1	13,138	20,900	19,619	8,115
7 ck.	...	...	...	1	10,436	15,925	15,418	7,155
8	...	625	4-10-4	1	11,913	19,225	19,236	7,840
9	...	625	4-10-0	1	11,480	19,077	19,450	8,055
10 ck.	...	...	...	1	10,177	15,410	15,911	7,305
11	...	400	0-16-0	1	11,345	16,960	17,498	7,775
12	...		†	1	9,778	16,465	17,547	7,525
13 ck.	...	...	...	1	8,911	14,875	15,702	7,325
14	...	160	nitrate of soda‡	1	9,182	16,120	16,004	7,515
15	...	160	nitrate of soda	1	9,128	16,070	16,295	7,580
16 ck.	...	...	...	1	8,571	13,690	13,579	7,245
21	...		(mulched)§	1	6,635	12,435	11,859	5,675
22 ck.	...	...	...	...	7,687	14,055	11,076	6,010
23	16	625	4-10-0	...	13,412	23,887	19,825	8,395
24	16	...	...	...	12,673	21,645	19,832	8,520
25	16	...	...	1	13,663	22,325	22,061	8,765
26	16	625	4-10-0	1	13,377	24,930	25,978	8,870
27	16	...	...	...	12,703	21,125	21,640	8,685
28	16	400	0-16-0	1	13,743	22,755	23,528	9,135
29 ck.	...	...	...	...	7,897	14,347	14,775	7,015
30	...	625	4-10-4	...	9,673	19,335	20,610	7,965
31	...	625	4-10-4	1	9,128	20,660	20,086	8,075
32 ck.	...	...	...	...	6,072	13,612	13,981	6,700
33	...	...	...	1	6,715	15,990	13,452	7,415
34	...	625	4-10-0	1	9,153	19,960	15,356	7,560
35	...	...	...	...	6,137	12,545	10,630	6,115
36	...	400	0-16-0	1	7,771	16,220	11,111	6,360

*Nitrogen—phosphoric acid—potash.

†Plot 12 received 80 pounds of nitrate of soda and 65 pounds of sulfate of ammonia per acre.

‡On plot 14, half of the nitrate of soda was applied before planting, half as a side dressing.

§Plot 21 was mulched with straw; no fertilizer was applied.

Results of the first 8 years.—The yields of the first 8 years have been reported in detail previously (1, 2). In brief (table 3), the application of 1,250 pounds per acre of 4-10-4 on plot 6 gave practically the same yield as an application of 16 tons of manure on plot 5. On the other hand, the highest yields of cabbage and cucumbers were on plot 26, where 16 tons of manure were supplemented with nitrogen and phosphate fertilizer.

Results of the second 8 years.—Because of severe drouth, all the crops were a failure in 1930; hence the yields for the 8 years, 1923-1930, are actually the averages of 7 years, 1923-1929 (table 4). The 1,875 pounds per acre of 4-10-4 on plot 8 gave a higher yield of cabbage than the 1,250 pounds on plot 6, but not of the other crops. Except with cabbage, these large applications of fertilizer did not give as high yields as were obtained from manure on plots 2, 3, or 5. Also, the fertilizer supplement to manure on plot 26 continued to give higher yields than 16 tons of manure alone, except with sweet corn. The increases in this case were probably due to the nitrogen fertilizer rather than to the phosphate, for a supplement of superphosphate alone, as on plot 28 or plot 2, did not give significant increases.

TABLE 4.—Average annual yield, 1923-1929

Plot	Annual application per acre				Average yield per acre			
	Manure	Fertilizer		Limestone	Tomatoes	Cabbage	Cucumbers	Sweet corn
		Amount	Formula					
	Tons	Lb.		Tons	Lb.	Lb.	Lb.	Lb.
1 ck.	...	...	...	1	9,346	19,069	12,860	7,663
2	16	800	0-16-0	1	13,180	24,360	21,623	9,023
3	16	...	...	1	12,896	24,263	21,754	9,263
4 ck.	...	...	...	1	8,937	20,691	15,423	7,931
5	20	...	...	1	12,790	26,166	21,794	9,469
6	...	1,250	4-10-4	1	11,834	28,463	18,274	8,023
7 ck.	...	...	...	1	8,617	20,817	12,249	6,874
8	...	1,875	4-10-4	1	11,271	30,286	16,071	7,069
9	...	1,250	4-10-0	1	10,314	26,863	14,617	7,131
10 ck.	...	...	...	1	8,176	20,189	9,746	6,714
11	...	800	0-16-0	1	8,551	20,863	9,669	6,891
12	...	260	sulfate of ammonia*	1	7,434	22,731	8,829	8,206
13 ck.	...	...	...	1	6,837	18,823	9,720	6,549
14	...	320	nitrate of soda†	1	8,157	24,034	10,563	7,503
15	...	320	nitrate of soda‡	1	7,994	23,263	10,360	7,331
16 ck.	...	...	...	1	7,103	18,646	8,743	6,229
21	8	1,250	4-10-4	1	11,740	25,074	19,606	8,434
22 ck.	...	...	...	...	7,157	13,646	10,154	6,023
23	16	625	4-10-0	...	13,237	27,560	21,500	9,583
24	16	...	...	...	12,734	25,829	23,331	9,200
25	16	...	...	1	12,237	26,794	24,383	10,097
26	16	625	4-10-0	1	13,794	29,960	28,217	9,777
27	16	...	...	...	13,277	26,023	24,446	10,091
28	16	400	0-16-0	1	12,707	26,583	23,703	9,589
29 ck.	...	...	...	...	7,314	14,663	11,954	6,349
30	...	625	4-10-4	...	9,374	21,629	16,297	7,749
31	...	625	4-10-4	1	9,819	23,931	13,854	7,360
32 ck.	...	...	...	...	5,733	12,571	7,743	5,880
33	...	...	...	1	5,820	15,571	5,886	6,400
34	...	625	4-10-0	1	8,163	22,731	7,183	6,897
35 ck.	...	...	...	...	6,109	12,434	5,640	5,737
36	...	400	0-16-0	1	6,646	17,400	5,571	6,080

*On cabbage and cucumbers, the application was 390 pounds of sulfate of ammonia per acre.

†Half was applied before planting, half as side dressing.

‡On cabbage and cucumbers, the application was 480 pounds of nitrate of soda per acre.

During the first 8 years, the omission of potash from the fertilizer on plot 9 had very little effect on yield, but during the second period, a deficiency became distinct on the crops, except sweet corn. Sweet corn with nothing but sulfate of ammonia, on plot 12, gave as high yields as with any of the complete fertilizers. Sweet corn thus showed a remarkable capacity to obtain its needed phosphorus and potassium from this soil.

With sweet corn, however, as well as with tomatoes and cucumbers, most of the manured plots gave somewhat higher yields than the fertilized plots. As this result might be due to the large amount of nitrogen supplied by 16 tons of manure per acre, and to its gradual nitrification during the growing season, the tests of the following 8 years were planned especially to determine the effect of increased amounts of nitrogen fertilizer, particularly in side dressings.

GENERAL RESULTS OF THE THIRD EIGHT YEARS

Weather conditions.—As a whole, the average yields of the third 8 years were not as high as those of the earlier years. For 7 years, 1931 to 1937 inclusive, the mean temperatures of June, July, and August were above normal (table 5). With a deficiency of rainfall in any one of these hot months, such as occurred in 1931, 1933, and 1936, the yield of all crops was affected. In 1936, sweet corn was almost a complete crop failure, and the data from that year were not included in the averages.

TABLE 5.—Mean monthly temperatures and monthly rainfall for 5 months of the crop season

	1931	1932	1933	1934	1935	1936	1937	1938	94-year average*
				Mean daily temperature					
April	52.4	52.2	55.6	54.0	51.7	50.1	54.0	54.4	53.4
May	62.3	64.4	67.3	66.0	60.8	66.2	63.6	60.6	63.1
June	72.6	73.4	75.0	77.6	71.1	73.8	74.0	67.1	70.8
July	79.5	76.3	75.5	79.8	78.7	77.8	75.2	73.5	74.5
August	74.1	74.1	74.6	74.0	75.6	77.6	76.8	76.3	73.7
				Rainfall in inches					
April	4.48	2.19	3.93	1.81	2.35	4.23	2.93	3.80	3.47
May	4.70	1.66	6.28	1.53	5.18	1.07	4.02	8.43	3.72
June	4.17	3.86	1.47	3.63	3.64	.96	5.27	4.06	4.46
July	2.04	3.56	3.58	5.37	5.82	3.20	4.16	2.98	4.51
August	3.54	5.40	3.34	4.92	12.65	2.36	3.96	3.74	3.92

*From records taken at Marietta, Ohio, reported in Climatological Data of the U. S. Weather Bureau.

Tests of the soil in 1931.—When the fertilizer plan was changed in the spring of 1931, soil samples were collected. Quick soil tests on some of these samples gave the data of table 6. It was found that the samples contained a large amount of phosphorus extractable in weak sulfuric acid solution by Truog's (6) procedure. Those limed plots which had had no phosphate fertilizer during the preceding 16 years showed 140 to 180 pounds of "available" phosphorus per 2,000,000 pounds of soil. Water extractions were then made, and it was found that the unfertilized plots showed 20 to 70 pounds of water-soluble phosphorus per 2,000,000 pounds of soil, and that the fertilized plots tested 100 to 130 pounds.

TABLE 6.—**Tests of soil samples collected in March 1931**

Tests made in 1938. Expressed in terms of 2,000,000 pounds of soil per acre

Plot	Phosphorus* applied in fertilizer in 16 years Lb. per acre	pH	Available phosphorus		Potassium* applied in fertilizer in 16 years Lb. per acre	Replaceable potassium, Thornton's method (5) Lb.
			Truog's method Lb.	Water soluble† Lb.		
6	892	6.8	350	130	662	400
7	none	6.9	180	70	none	100
8	892	6.8	400	130	662	300
9	669	6.8	300	120	none	75
10	none	6.9	140	60	none	50
23	892‡	5.2	250	90	2,446‡	600
25	446‡	6.9	220	90	2,116‡	600
29	none	5.3	90	30	none	75
30	446	5.5	170	80	331	100
31	446	7.0	180	120	331	150
32	none	5.6	90	20	none	75
33	none	7.0	140	50	none	50
34	446	7.1	200	150	none	50
35	none	5.3	90	30	none	100

*Based on the guaranteed analyses of the fertilizer. Note that all the calculations of this table are in terms of phosphorus and potassium, not phosphoric acid and potash.

†Determined by suspending 1 gram of soil in 200 milliliters of water, shaking, allowing to stand over night, then proceeding as in the Truog method.

‡Assuming that the manure contained 4 pounds of phosphoric acid and 10 pounds of potash per ton.

Effect of residual phosphorus on yield of all crops.—The most striking result of the third 8 years was the sustained yield on plot 31, where phosphate was omitted from the fertilizer. In agreement with the findings of the soil tests, this plot contained sufficient residual available phosphorus to maintain the crops for 4 years or more after the phosphate application had been discontinued. Hence, the average yields for the entire 8 years on plot 31 were almost as high as those on continuously phosphated plot 34 (table 7).

In contrast, the check plots fertilized first in 1931, did not give as high yields as the continuously fertilized plots for 4 or 5 years, except with sweet corn. The appearance of the crops indicated deficiency of phosphorus.

Since the soil tests indicated that all the plots which were phosphated during the first 16 years contained as much residual phosphorus as plot 31, and since the plots which were unphosphated must have been deficient in available phosphorus to the same degree as the check plots, there is some difficulty in evaluating the effect of the fertilizers applied after 1931. The residual effects had largely disappeared by the seventh year, however, and consequently, in the tables that follow, the average yields of the seventh and eighth years are included and used as a basis for some of the deductions.

RESULTS WITH THE INDIVIDUAL CROPS

In presenting the yields of the individual crops, the data of table 7 are rearranged to show more clearly the comparative effect of various amounts of each fertilizer constituent. To show the cumulative effect of the treatments started in 1931, the average yields of the last 2 years, 1937 and 1938, are included.

CABBAGE

As this soil is naturally acid, liming, tested during the first 15 years, increased the yield of cabbage (table 8). In 1931, the previously unlimed plots were given 8 tons of ground limestone per acre; hence the data of the following tables all are from heavily limed soil.

TABLE 7.—Average annual yield, third 8 years, 1931-1938

Increase or decrease compared with uniformly fertilized check plots

Plot	Fertilizer treatment per acre					Average yield per acre								Plot
	Applied before planting			Side dressings*		Cabbage		Tomatoes		Cucumbers		Sweet corn		
	Manure	Fertilizer												
	Tons	Lb.	Formula	No.	Total Lb.	Yield Lb.	Increase or decrease Lb.	Yield Lb.	Increase or decrease Lb.	Yield Lb.	Increase or decrease Lb.	Yield Lb.	Increase or decrease Lb.	
1 ck	....	1,000	8-12- 8	2	400	23,875	....	9,239	....	6,865	....	6,485	....	1
2	8	1,000	0- 8- 0	......	....	21,755	-2,552	10,914	1,666	11,853	4,480	6,874	450	2
3	8	1,000	8- 8- 0	2	400	26,840	2,102	10,947	1,689	10,208	2,328	7,217	865	3
4 ck	....	1,000	8-12- 8	2	400	25,170	....	9,268	....	8,568	....	6,280	....	4
5	16	1,000	8- 8- 0	3	600	27,680	2,705	10,300	1,278	11,530	3,093	7,737	1,889	5
6	....	1,500	8-12- 8	2	600	27,570	2,790	9,764	988	9,250	937	6,628	1,213	6
7 ck	....	1,000	8-12- 8	2	400	24,585	....	8,530	....	8,198	....	4,983	....	7
8	....	1,000	8-12-24	2	400	26,120	1,693	9,455	924	9,421	1,463	4,983	-121	8
9	....	1,000	8-12-16	2	400	26,250	1,982	9,183	651	9,098	1,378	5,714	491	9
10 ck	....	1,000	8-12- 8	2	400	24,110	....	8,533	....	7,480	....	5,674	....	10
11	....	1,000	8-12- 0	2	400	17,815	-6,492	7,964	-865	4,530	-2,974	4,891	-771	11
12	....	1,000	8-12- 8	3	600	24,350	-153	9,475	349	7,995	468	6,434	783	12
13 ck	....	1,000	8-12- 8	2	400	24,700	....	9,367	....	7,550	....	5,640	....	13
14	....	1,000	8-12- 8	1	200	23,675	-702	9,107	-59	7,260	120	5,720	-213	14
15	....	1,000	8-12- 8	......	....	21,725	-2,328	9,318	353	6,345	-385	5,114	-1,124	15
16 ck	....	1,000	8-12- 8	2	400	23,730	....	8,764	....	6,320	....	6,537	....	16
21	8	1,000	8- 8-16	......	....	24,555	190	10,313	1,485	9,768	1,643	6,223	274	21
22 ck	....	1,000	8-12- 8	2	400	24,365	....	8,828	....	8,125	....	5,949	....	22
23	8	1,000	8-24- 0	......	....	26,055	1,591	10,611	1,775	11,810	3,643	7,794	1,813	23
24	8	1,000	8-16- 0	......	....	26,195	1,631	10,280	1,436	13,465	5,256	7,549	1,535	24
25	8	1,000	8- 0- 0	......	....	25,710	1,047	9,790	937	14,235	5,984	7,829	1,782	25
26	8	1,000	8- 8- 0	......	....	27,365	2,603	10,468	1,600	13,775	5,482	8,126	2,047	26
27	16	....	....	......	....	23,015	-1,846	9,551	682	14,360	6,024	7,537	1,425	27
28	16	1,000	8- 6- 4	......	....	28,615	3,654	10,666	1,788	12,880	4,509	8,109	1,964	28
29 ck	....	1,000	8-12- 8	2	400	25,060	....	8,887	....	8,420	....	6,177	....	29
30	....	500	8-12- 8	......	....	20,975	-3,137	8,203	-459	6,680	-738	4,269	-1,569	30
31	....	1,000	8- 0- 8	2	400	25,120	1,957	8,526	88	6,723	306	5,583	84	31
32 ck	....	1,000	8-12- 8	2	400	22,215	....	8,213	....	5,415	....	5,160	....	32
33	....	none	....	2	....	6,990	-15,077	4,755	-3,415	1,988	-3,293	3,171	-1,962	33
34	....	1,000	8-20- 8	2	400	24,190	2,272	8,778	651	6,035	888	5,337	230	34
35 ck	....	1,000	8-12- 8	2	400	21,770	....	8,084	....	5,013	....	5,080	....	35
36	....	1,000	0-12- 8	......	....	13,490	-8,280	6,879	-1,205	4,583	-430	3,446	-1,634	36

*Of sulfate of ammonia.

Fertilizers without manure, table 9.—Nitrogen fertilizer proved to be particularly necessary for cabbage. The highest average yield in the nitrogen series was on the plot with two side applications in addition to 80 pounds of nitrogen per acre in the initial fertilizer. The first side dressing of sulfate of ammonia was applied to cabbage about 2 weeks after the plants were set in the field, and succeeding applications were made at intervals of about 2 weeks.

As would be expected, the value of the side applications varied with the seasons (table 10). In years of ample rainfall during May and June, consequently seasons of high yields, two side dressings resulted in average increases of about 4,000 pounds per acre, whereas in three seasons with dry weather in May, none of the side dressings had much effect.

In the phosphate series, the residue from previous applications on plot 31 supplied ample phosphorus for the cabbage plants for the entire 8 years; the yields were as high as on continuously phosphated plot 34.

Potash fertilizer had very little effect on cabbage yields before 1931, but after that gave pronounced increases. The average yields of the two high-potash treatments in the last 2 years showed that more than 8 per cent of potash was required for maximum yields.

In the quantity series, the average yield from the 1,500-pound application of 8-12-8 (plot 6) was higher than that from any other unmanured plot. The increase over other high-yielding plots (8, 9, 31, and 34) was statistically significant. As plot 6 received a larger amount of nitrogen in the initial fertilizer than any other plot, the higher yield was probably due to the initial application of 120 pounds of nitrogen per acre.

Fertilizers with manure, table 11.—With manure, nitrogen in the initial fertilizer gave a large increase in yield, but additional nitrogen applied as side dressings had little or no effect except in seasons of very high yields.

In the phosphate series, the results of the last 2 years show that 8 tons of manure did not supply sufficient phosphate to maintain the yields of cabbage.

Potash fertilizer appears to have caused a decrease in yield, but the comparison is not reliable, because plot 21 is at the end of the field where standing water sometimes injured the crops.

The 16 tons of manure per acre applied to plot 27 did not supply sufficient nitrogen early in the season; the deficiency appeared to be the same as with 8 tons of manure on plot 2. The benefits from the complete fertilizer with 16 tons of manure were probably due solely to the 80 pounds of nitrogen supplied.

The yield from 16 tons of manure supplemented with fertilizer was not consistently higher than that from 8 tons with nitrogen side dressings on plot 3.

Deductions and recommendations.—As 1,500 pounds per acre of 8-12-8 gave the highest yield in the unmanured series, this would be the recommended fertilizer for early cabbage, unless soil is at the high phosphate level of most of the plots in this experiment. On the other hand, since 400 pounds of 16 per cent superphosphate per acre applied for 16 years resulted in an accumulation of available phosphorus, not more than this would be needed in a regular fertilizer program. Thus, a fertilizer with the unusual ratio of 8-4-8, applied at the rate of 1,500 pounds per acre, should prove satisfactory on the soil in this district.

In seasons with ample rainfall in May, two side dressings of 200 pounds per acre of sulfate of ammonia, or its equivalent, are recommended.

TABLE 8.—Effect of liming on yield, 1915-1929

Plot	Treatment per acre	pH in 1930	Average annual yield per acre			
			Cabbage Lb.	Tomatoes Lb.	Cucumbers Lb.	Sweet corn Lb.
31	625 lb. of 4-10-4, limed	7.0	22,186	9,450	17,178	7,741
30	625 lb. of 4-10-4, unlimed	5.5	20,405	9,533	18,597	7,864
	Increase or decrease due to liming	....	1,781	-83	-319	-123
25	16 tons of manure, limed	6.9	24,411	12,998	23,145	9,387
24	16 tons of manure, unlimed	5.4	23,598	12,701	21,465	8,837
	Increase or decrease due to liming	....	813	297	1,680	550

TABLE 9.—Effect of fertilizer without manure on yield of cabbage

Increase or decrease compared with uniformly fertilized check plots

Plot	Fertilizer treatments			Average of 8 years, 1931-1938		Average of 2 years, 1937-1938	
	Before planting 1,000 lb. per acre	Side dressings No.	Side dressings Total Lb.	Yield per acre Lb.	Increase or decrease* Lb.	Yield per acre Lb.	Increase or decrease Lb.
			Nitrogen series				
36	0-12- 8	....	....	13,490	-8,280	16,740	-13,700
15	8-12- 8	....	....	21,725	-2,328	26,780	-4,473
14	8-12- 8	1	200	23,675	-702	28,900	-3,107
13 ck	8-12- 8	2	400	24,700	....	32,760	....
12	8-12- 8	3	600	24,350	-153	31,380	-780
			Phosphate series				
31	8- 0- 8	2	400	25,120	1,957	33,000	1,240
32 ck	8-12- 8	2	400	22,215	....	31,740	....
34	8-20- 8	2	400	24,190	2,272	31,920	1,047
			Potash series				
11	8-12- 0	2	400	17,815	-6,492	23,980	-7,580
10 ck	8-12- 8	2	400	24,110	....	30,960	....
9	8-12-16	2	400	26,250	1,982	33,120	1,707
8	8-12-24	2	400	26,120	1,693	32,880	1,013
			Quantity series				
	8-12-8 per acre Lb.						
33	none	....	....	6,990	-15,077	7,700	-23,607
30	500	....	....	20,975	-3,137	25,820	-5,960
29 ck	1,000	2	400	25,060	....	31,800	....
6	1,500	2	600	27,570	2,790	34,640	2,287

*An increase of about 2,000 pounds is required for statistical significance (see table 2).

TABLE 10.—Seasonal difference in the effect of side applications of nitrogen fertilizer on yield of cabbage

Seasons listed according to the amount of rainfall during May

Year	Rainfall		Yield per acre with—			
	May In.	June In.	No side dressing Lb.	One side dressing Lb.	Two side dressings Lb.	Three side dressings Lb.
1938	8.43	4.06	19,200	19,720	24,600	23,600
1933	6.28	1.47	18,520	21,080	20,760	21,280
1935	5.18	3.64	28,520	30,800	34,080	33,600
1931	4.70	4.17	36,960	41,560	39,640	39,920
1937	4.02	5.27	34,360	38,080	40,920	39,160
Average of five wet seasons			27,512	30,248	32,000	31,512
Increase			....	2,736	4,488	4,000
1932	1.66	3.86	17,240	17,440	17,360	17,840
1934	1.53	3.63	12,200	12,840	12,880	11,800
1936	1.07	.96	6,800	7,880	7,360	7,600
Average of three dry seasons			12,080	12,720	12,533	12,413
Increase			....	640	453	333

TABLE 11.—Effect of fertilizers with manure on yield of cabbage

Increase in yield compared with uniformly fertilized check plots

Plot	Manure per acre	Fertilizer		Average of 8 years, 1931–1938		Average of 2 years, 1937–1938	
	Tons	Before planting 1,000 lb. per acre	Side dressings No.	Yield per acre Lb.	Increase or decrease Lb.	Yield per acre Lb.	Increase or decrease Lb.
Nitrogen series							
2	8	0- 8- 0	....	21,755	-2,552	25,560	-7,913
26	8	8- 8- 0	....	27,365	2,603	30,980	-1,582
3	8	8- 8- 0	2	26,840	2,102	34,040	1,093
Phosphate series							
25	8	8- 0- 0	....	25,710	1,047	26,300	-6,517
26	8	8- 8- 0	....	27,365	2,603	30,980	-1,582
24	8	8-16- 0	....	26,195	1,631	31,180	-1,891
23	8	8-24- 0	....	26,055	1,591	32,140	-1,186
Potash series							
26	8	8- 8- 0	....	27,365	2,603	30,980	-1,582
21	8	8- 8-16	....	24,555	190	32,600	-980
With 16 tons of manure							
27	16	....	....	23,015	-1,846	24,880	-7,428
28	16	8- 6- 4	....	28,615	3,654	33,100	1,046
5	16	8- 8- 0	3	27,680	2,705	35,600	3,213

With manure, at the rate of either 8 tons or 16 tons per acre, some nitrogen fertilizer is needed at the time of setting the plants. Since cabbage has been so responsive to initial nitrogen applications, the amount used here, 80 pounds of nitrogen per acre, about 400 pounds of sulfate of ammonia, is recommended. With only 8 tons of manure per acre, some phosphate fertilizer is also needed. The amount cannot be stated definitely, but 100 to 200 pounds per acre of 20 per cent superphosphate would probably suffice.

TOMATOES

The early pickings of tomatoes usually bring high prices; consequently, in order to ripen the first few clusters rapidly and evenly, the plants have been pruned to a single stem, and tied to stakes. This has long been the standard practice in the Marietta district. It results in good quality and early fruit, but in rather low total yields.

Occasionally in recent years, the tomato fruit worm has been serious, making a large proportion of the tomatoes unsalable. In such seasons, the data from a fertilizer experiment would be practically valueless if the wormy fruits were discarded; consequently, they were included in the data if they were otherwise marketable.

TABLE 12.—Effect of fertilizer without manure on yield of tomatoes

Increase or decrease compared with uniformly fertilized check plots

Plot	Fertilizer treatment			Average of 8 years, 1931-1938		Average of 2 years, 1937-1938	
	Before planting 1,000 lb. per acre	Side dressings					
		No.	Total Lb.	Yield per acre Lb.	Increase or decrease* Lb.	Yield per acre Lb.	Increase or decrease Lb.
				Nitrogen series			
36	0-12- 8	....	....	6,879	-1,205	8,610	-3,230
15	8-12- 8	....	....	9,318	353	9,040	1,780
14	8-12- 8	1	200	9,107	-59	9,700	-700
13 ck	8-12- 8	2	400	9,367	....	9,980	....
12	8-12- 8	3	600	9,475	349	10,840	977
				Phosphate series			
31	8- 0- 8	2	400	8,526	88	10,710	-903
32 ck	8-12- 8	2	400	8,213	....	11,310	....
34	8-20- 8	2	400	8,778	651	11,990	326
				Potash series			
11	8-12- 0	2	400	7,964	-865	9,810	64
10 ck	8-12- 8	2	400	8,533	....	9,630	....
9	8-12-16	2	400	9,183	651	11,300	1,553
8	8-12-24	2	400	9,455	924	11,000	1,137
				Quantity series			
	8-12-8 per acre Lb.						
33	none	....	....	4,755	-3,415	6,990	-4,497
30	500	....	....	8,203	-459	10,460	-1,457
29 ck	1,000	2	400	8,887	....	12,220	....
6	1,500	2	600	9,764	988	10,690	690

*An increase of about 1,000 pounds is required for statistical significance (see table 2).

Fertilizers without manure, table 12.—Nitrogen in the initial fertilizer increased the yield, but further applications as side dressings had insignificant effects in most seasons. Only in 1937 and 1938, with heavy rains in May, was there any increase in yield from the side dressings, and this did not occur in other seasons of heavy rains.

In the phosphate series, the yield was maintained by the residual phosphorus of plot 31 for only 4 years. After this there was a decline in yield in comparison with continuously phosphated plot 34. The residual phosphorus was evidently not as available to tomatoes as to cabbage. On the other hand, the fertilizer applications on many of the check plots seemed to be fully effective by the fifth year.

In the potash series, the heavily fertilized plots 8 and 9 gave larger yields than the check plots. The yields were as high on these plots as from the 1,500 pounds of 8-12-8 on plot 6.

Fertilizers with manure, table 13.—With 8 tons of manure per acre, neither nitrogen nor potash fertilizer increased the yield of tomatoes.

TABLE 13.—Effect of fertilizers with manure on yield of tomatoes

Increase in yield compared with uniformly fertilized check plots

Plot	Manure per acre	Fertilizer		Average of 8 years, 1931–1938		Average of 2 years, 1937–1938	
		Before planting 1,000 lb. per acre	Side dressings	Yield per acre	Increase or decrease	Yield per acre	Increase or decrease
	Tons		No.	Lb.	Lb.	Lb.	Lb.
			Nitrogen series				
2	8	0- 8- 0	....	10,914	1,666	11,750	903
26	8	8- 8- 0	....	10,468	1,600	11,070	128
3	8	8- 8- 0	2	10,947	1,689	11,130	687
			Phosphate series				
25	8	8- 0- 0	....	9,790	937	10,670	153
26	8	8- 8- 0	....	10,468	1,600	11,070	128
24	8	8-16- 0	....	10,280	1,436	10,150	59
23	8	8-24- 0	....	10,611	1,775	10,980	1,315
			Potash series				
26	8	8- 8- 0	....	10,468	1,600	11,070	128
21	8	8- 8-16	....	10,313	1,485	10,560	1,320
			With 16 tons of manure				
27	16	....	....	9,551	682	10,130	-1,238
28	16	8- 6- 4	....	10,666	1,788	12,240	447
5	16	8- 8- 0	3	10,300	1,278	10,570	550

The results from superphosphate with manure are on the threshold of significance. No distinct symptoms of phosphorus deficiency have appeared on plot 25. On the other hand, the adjacent phosphated plots, 24 and 26, have yielded at the rate of about 500 pounds per acre more than plot 25, and the odds are about 30 to 1 that the increases were not due to chance.

With 16 tons of manure per acre, the plants on plot 27 showed symptoms of nitrogen deficiency in several seasons. This deficiency developed with 16 tons, but not with 8 tons, per acre. In the earlier years of the experiment, this deficiency was corrected by an application of 160 pounds of nitrate of soda, supplying only 25 pounds of nitrogen per acre (compare plots 26 and 28 in table 4). The benefit from a complete fertilizer with the manure on plot 28 is thus probably due solely to the available nitrogen supplied. The yield on plot 28 was not significantly higher than that of most of the plots with 8 tons of manure per acre.

Deductions and recommendations.—Tomatoes require relatively little nitrogen fertilizer. The 80 pounds per acre used here in the initial fertilizer proved ample. Probably less would have sufficed. In the preceding years of the experiment, 1,250 pounds of 4-12-4, supplying only 50 pounds of nitrogen, gave as high yields as 1,875 pounds per acre of the same fertilizer (see table 4, plots 6 and 8). These results agree with general experience; hence, 50 pounds of nitrogen in the initial fertilizer are recommended.

The amount of phosphoric acid required in a fertilizer is not clearly evident from the data. The deductions are about the same as for cabbage, and similarly, about 60 pounds per acre (300 pounds of 20 per cent superphosphate) may be recommended in a fertilizer for soil at the high phosphate level of the soil in this experiment. On soils low in phosphorus, very large amounts are commonly used and recommended for tomatoes.

The 1,500-pound application of 8-12-8 appeared to supply ample potash; the yield with it was as high in the 8-year averages as that on the high-potash plots. Hence, the amount recommended is 120 pounds per acre.

A complete fertilizer for tomatoes, then, would be 1,000 pounds per acre of 5-6-12. Side dressings are not likely to be needed.

With 8 tons of manure per acre, some phosphate fertilizer may be needed. Probably 100 to 200 pounds of 20 per cent superphosphate would be ample.

With 16 tons of manure per acre, a small amount of nitrogen fertilizer may be needed. Presumably, the more strawy the manure, the more nitrogen fertilizer would be required.

In the early years of the experiment, liming had no appreciable effect on the yield. Tomatoes tolerated a range of soil reaction from pH 5.0 to 7.2.

CUCUMBERS

The results with cucumbers have been the least satisfactory of the four crops. The stand and growth of plants were rarely uniform. Injury from insects and diseases varied from plot to plot. During the rush of the harvest season, some injury from stepping on the vines was practically unavoidable.

From the experiment as a whole, the conspicuous result has been the response to manure in unfavorable seasons (table 14). Only in the most favorable season did the fertilized plots yield as well as the manured plots; in the last 8 years there were five seasons with low yields. In these unfavorable seasons, the yields were so low on the unmanured plots that the fertilizer differences were of little significance. On the other hand, in the three favorable seasons, the effect of the fertilizers showed clearly. The last 2 years were favorable seasons, however, and the effects of the fertilizers can be seen from the data of these years in the following tables.

Fertilizers without manure, table 15.—In the 8-year average yields, the only distinct response of cucumbers to fertilizers was to potash. From the data of the last 2 years, however, further deductions can be drawn.

TABLE 14.—Seasonal differences in the benefits from manure on cucumbers

Seasons listed in the order of the magnitude of the yield per acre on the fertilized plot

Season	Fertilized Plot 6 Lb.	Manured Plot 5 Lb.	Increase or decrease of plot 5 over plot 6	
			Lb.	Per cent
1937	25,760	22,960	-2,800	-10.9
1938	13,280	14,560	1,280	9.6
1933	12,120	17,520	5,400	44.6
1932	9,440	14,040	4,600	48.7
1936	4,360	6,120	1,760	40.4
1931	3,480	5,200	1,720	49.4
1934	2,840	5,720	2,880	101.4
1935	2,720	6,120	3,400	125.0
Average	9,250	11,530	2,280	24.6

TABLE 15.—Effect of fertilizer without manure on yield of cucumbers

Increase or decrease compared with uniformly fertilized check plots

Plot	Fertilizer treatments			Average of 8 years, 1931–1938		Average of 2 years, 1937–1938	
	Before planting 1,000 lb. per acre	Side dressings No.	Side dressings Total Lb.	Yield per acre Lb.	Increase or decrease* Lb.	Yield per acre Lb.	Increase or decrease Lb.
			Nitrogen series				
36	0–12– 8	....	....	4,583	-430	8,480	-4,000
15	8–12– 8	....	....	6,345	-385	13,860	-1,100
14	8–12– 8	1	200	7,260	120	15,370	320
13 ck	8–12– 8	2	400	7,550	....	15,130	....
12	8–12– 8	3	600	7,995	468	15,100	-720
			Phosphate series				
31	8– 0– 8	2	400	6,723	306	11,630	-1,730
32 ck	8–12– 8	2	400	5,415	....	13,600	....
34	8–20– 8	2	400	6,035	888	15,650	3,400
			Potash series				
11	8–12– 0	2	400	4,530	-2,974	9,940	-6,570
10 ck	8–12– 8	2	400	7,480	....	17,200	....
9	8–12–16	2	400	9,098	1,378	20,150	2,360
8	8–12–24	2	400	9,421	1,463	21,190	2,810
			Quantity series				
	8–12–8 per acre Lb.						
33	none	....	....	1,988	-3,293	3,560	-8,450
30	500	....	....	6,680	-738	10,160	-4,780
29 ck	1,000	2	400	8,420	....	16,520	....
6	1,500	2	600	9,250	937	19,520	1,090

*An increase of about 2,600 pounds is required for statistical significance (see table 2).

Nitrogen in the initial fertilizer was effective. The first side dressing, applied when the first true leaves were unfolded, further increased the yield, but later side dressings did not.

In the phosphate series, continuously phosphated plot 34 outyielded the check, showing that the 120 pounds of phosphoric acid applied to the check plot annually, beginning in 1931, did not supply ample phosphorus even in the seventh and eighth years.

In the potash series, the plots with the heavy applications outyielded the check plot. These plots, however, had been continuously phosphated, and the increase over the checks may have been due to adequate phosphorus rather than to the additional potash. That 8 per cent of potash was probably sufficient is indicated by the fact that 8-20-8 on plot 34 gave practically the same increase over the checks as resulted from the higher potash applications on plots 8 and 9.

Fertilizers with manure, table 16.—With 8 tons of manure per acre, there was no significant increase in yield of cucumbers from the use of additional fertilizer. Larger quantities of phosphoric acid resulted in increasing yields the last 2 years, but the 8-year average showed a reverse sequence and, consequently, both results are of doubtful significance.

TABLE 16.—Effect of fertilizers with manure on yield of cucumbers

Increase in yield compared with uniformly fertilized check plots

Plot	Manure per acre	Fertilizer		Average of 8 years, 1931-1938		Average of 2 years, 1937-1938	
		Before planting 1,000 lb. per acre	Side dressings	Yield per acre	Increase or decrease	Yield per acre	Increase or decrease
	Tons		No.	Lb.	Lb.	Lb.	Lb.
Nitrogen series							
2	8	0- 8- 0	....	11,852	4,480	17,770	2,800
26	8	8- 8- 0	....	13,775	5,482	19,110	2,110
3	8	8- 8- 0	2	10,208	2,328	17,970	1,810
Phosphate series							
25	8	8- 0- 0	....	14,235	5,984	19,040	1,870
26	8	8- 8- 0	....	13,775	5,482	19,110	2,110
24	8	8-16- 0	....	13,465	5,256	19,900	2,570
23	8	8-24- 0	....	11,810	3,643	20,280	2,790
Potash series							
26	8	8- 8- 0	....	13,775	5,482	19,110	2,110
21	8	8- 8-16	....	9,768	1,643	17,840	190
With 16 tons of manure							
27	16	....	....	14,360	6,024	18,780	1,940
28	16	8- 6- 4	....	12,880	4,509	18,200	1,520
5	16	8- 8- 0	3	11,530	3,093	18,750	850

Sixteen tons of manure per acre did not give higher yields than the 8-ton applications.

Deductions and recommendations.—Eight tons of manure per acre applied annually, with no other fertilizer, gave as good yields as any of the fertilizer treatments in favorable seasons, and considerably better yields in unfavorable seasons. Moreover, 8 tons of manure proved as effective as 16 tons per acre. The obvious recommendation is to grow cucumbers on fields that have been regularly manured.

A fertilizer to use without manure is difficult to determine from these conflicting results. The fertilizer constituents supplied by 8 tons of manure approximate 1,000 pounds of 8-4-8. Hence a fertilizer of this formula would be advised were it not for the fact that cucumbers were unable to use the phosphorus from superphosphate as effectively as that from manure. Even on a soil with considerable available phosphorus, it seems necessary to apply more phosphate fertilizer for cucumbers than for other crops. A tentative recommendation for cucumbers on such soil is 1,000 pounds per acre of 8-8-8, with one side dressing of nitrogen fertilizer.

SWEET CORN

The crop of sweet corn was a total failure in 1936; hence the data of tables 17 and 18 are averages of 7 instead of 8 years. In 1931, the crop was very poor, but considerably better on manured than on unmanured plots. Largely because of the 1931 results, the manured plots averaged higher yields than the best of the fertilized plots.

Fertilizers without manure, table 17.—Nitrogen in the fertilizer applied before planting raised the 7-year average yield only 500 pounds per acre. The most effective nitrogen application was the first side dressing, applied when the

TABLE 17.—Effect of fertilizer without manure on yield of sweet corn

Increase or decrease compared with uniformly fertilized check plots

Plot	Fertilizer treatments			Average of 7 years, 1931–1938*		Average of 2 years, 1937–1938	
	Before planting 1,000 lb. per acre	Side dressings					
		No.	Total Lb.	Yield per acre Lb.	Increase or decrease† Lb.	Yield per acre Lb.	Increase or decrease Lb.
				Nitrogen series			
36	0-12- 8	....	....	3,446	-1,634	4,560	-3,560
15	8-12- 8	....	....	5,114	-1,124	6,720	-860
14	8-12- 8	1	200	5,726	-213	6,880	-340
13 ck	8-12- 8	2	400	5,640	....	6,860	....
12	8-12- 8	3	600	6,434	783	8,060	1,093
				Phosphate series			
31	8- 0- 8	2	400	5,583	84	8,460	-180
32 ck	8-12- 8	2	400	5,160	....	8,320	....
34	8-20- 8	2	400	5,337	230	8,840	653
				Potash series			
11	8-12- 0	2	400	4,891	-771	6,160	-914
10 ck	8-12- 8	2	400	5,674	....	7,180	....
9	8-12-16	2	400	5,714	491	7,240	314
8	8-12-24	2	400	4,983	-121	6,000	-673
				Quantity series			
	8-12-8 per acre Lb.						
33	none	....	....	3,171	-1,962	5,000	-3,254
30	500	....	....	4,269	-1,569	6,040	-2,920
29 ck	1,000	2	400	6,177	....	9,280	....
6	1,500	2	600	6,628	1,213	7,760	1,000

*Not including 1936.
†An increase of about 1,700 pounds is required for statistical significance (see table 2).

plants were about 18 inches tall. The third side dressing, applied early in July, was effective in seasons of high yields. The average increase in three such seasons (1932, 1933, and 1937) was 1,200 pounds per acre.

Phosphate in the fertilizer has never, in the entire course of the experiment, given significant increases in the yield of sweet corn.

The increase from potash fertilizer on the check plot is significant statistically. The odds are about 100 to 1 that the increase was not due to chance variation.

In the quantity series, the high yield from the 1,500 pounds of 8-12-8 is rather difficult to explain. A year-by-year comparison with other plots shows that this treatment gave an outstanding yield in 1935, a season with cold, wet weather in May, and hot, rainy weather in July. It may have been that the rains leached out nitrates, so that 300-pound side dressings were more effective than the 200-pound applications.

Fertilizers with manure, table 18.—The effects of fertilizers with manure are somewhat difficult to interpret, because plot 26 has been peculiarly high in yield, and this plot is included in three of the comparisons of table 18.

TABLE 18.—Effect of fertilizers with manure on yield of sweet corn

Increase in yield compared with uniformly fertilized check plots

Plot	Manure per acre	Fertilizer		Average of 7 years, 1931-1938*		Average of 2 years, 1937-1938	
	Tons	Before planting 1,000 lb. per acre	Side dressings No.	Yield per acre Lb.	Increase or decrease Lb.	Yield per acre Lb.	Increase or decrease Lb.
				Nitrogen series			
2	8	0- 8- 0	....	6,874	450	5,960	-1,480
26	8	8- 8- 0	....	8,126	2,047	9,780	776
3	8	8- 8- 0	2	7,217	865	7,840	400
				Phosphate series			
25	8	8- 0- 0	....	7,829	1,782	9,940	1,022
26	8	8- 8- 0	....	8,126	2,047	9,780	776
24	8	8-16- 0	....	7,549	1,535	9,600	768
23	8	8-24- 0	....	7,794	1,813	9,520	774
				Potash series			
26	8	8- 8- 0	....	8,126	2,047	9,780	776
21	8	8- 8-16	....	6,223	274	8,620	-40
				With 16 tons of manure			
27	16	....	....	7,537	1,425	9,360	270
28	16	8- 6- 4	....	8,109	1,964	10,220	1,044
5	16	8- 8- 0	3	7,737	1,889	8,480	1,380

*Not including 1936.

Nitrogen included in the initial fertilizer increased the yield, but further applications as side dressings did not.

In the phosphate series, none of the phosphated plots distinctly outyielded plot 25.

The inclusion of potash in the fertilizer appeared to reduce the yield, but the lower yield on plot 21 was probably due to the location of the plot at the end of the field, rather than to the potash.

With 16 tons of manure, the addition of a complete fertilizer increased the yield about 500 pounds per acre. This increase was fairly consistent, giving odds of over 1,000 to 1 that it was not due to chance variation. The increase was probably due to the nitrogen. If so, this is another instance in which some initial nitrogen fertilizer was effective with 16 tons of manure but not with 8 tons of manure per acre.

Deductions and recommendations.—In the last 8 years, the effect of nitrogen in the initial fertilizer has hardly been significant, but in earlier years, 50 pounds of nitrogen per acre gave such good results that it seems reasonable to continue to advise about 50 pounds of nitrogen in the preplanting fertilizer mixture (note plots 12 and 15 in table 4). Potash is also needed at the rate of about 80 pounds per acre. The fertilizer mixture for an acre might be made from 250 pounds of sulfate of ammonia and 160 pounds of 50 per cent muriate of potash.

Side dressings of sulfate of ammonia have been particularly valuable on sweet corn. From the results to date, 200 or 300 pounds of sulfate of ammonia per acre should be applied when the plants are about 18 inches tall, and a second application, a month later.

With manure, some nitrogen fertilizer may be needed at the time of planting if the manure is strawy, or if it is heavily applied.

SUMMARY OF THE RECOMMENDATIONS

The recommendations of the preceding pages are summarized in table 19. The differences in the requirements of the four crops show clearly in this table.

TABLE 19.—Summary of the recommendations

Crop	Without manure						
	Initial fertilizer					Side dressings*	
	Formula	Rate per acre	Nutrients per acre			Number	Total nitrogen in side dressings
			Nitrogen	Phosphoric acid	Potash		
		Lb.	Lb.	Lb.	Lb.		Lb.
Cabbage......	8- 4- 8	1,500	120	60	120	2	80
Tomatoes.....	5- 6-12	1,000	50	60	120	none	....
Cucumbers....	8- 8- 8	1,000	80	80	80	1	40
Sweet corn.....	5- 0- 8	1,000	50	none	80	2	100
	With 8 tons of manure per acre						
Cabbage......	8- 4- 0	1,000	80	40	none	1	40
Tomatoes.....	0-20- 0	200	none	40	none	none	....
Cucumbers....	....	none	....	....	....	none	....
Sweet corn.....	21- 0- 0	125	25	none	none	none	....

*Of 200 pounds per acre of sulfate of ammonia or its equivalent. Side dressing is advised only for seasons of ample rainfall.

Although these recommendations may need to be modified according to the fertility level of the soil, as pointed out in the following discussion, the comparative differences in the requirements of the individual crops remain.

Home mixing of fertilizer.—As low-phosphorus fertilizers, such as recommended here, are not on the market, growers who wish to use these must have them mixed to order or mix them at home from the ingredients listed in table

20. One difficulty with home-mixed fertilizers is that they soon harden. It may be more practical to use as a base a commercial fertilizer high in potash, and to add nitrogen. For example, to make the equivalent of 1,500 pounds of 8-4-8 for cabbage, 750 pounds of 0-8-16 could be mixed with 600 pounds of sulfate of ammonia. Likewise, for tomatoes, 750 pounds of 0-8-16 mixed with 250 pounds of sulfate of ammonia would be equivalent to the 1,000 pounds of 5-6-12 recommended here.

TABLE 20.—Ingredients for home mixing the fertilizers recommended*

Crop	Fertilizer to be applied before planting					Sulfate of ammonia to be applied in side dressings†
			Ingredients for an acre			
	Formula	Rate per acre	Sulfate of ammonia	Super-phosphate, 20 per cent	Muriate of potash, 50 per cent	
		Lb.	Lb.	Lb.	Lb.	Lb.
Fertilizer without manure						
Cabbage..........	8- 4- 8	1,500	600	300	240	400
Tomatoes.........	5- 6-12	1,000	250	300	240	none
Cucumbers........	8- 8- 8	1,000	400	400	160	200
Sweet corn.........	5- 0- 8	1,000	250	none	160	500
Fertilizer with 8 tons of manure per acre						
Cabbage..........	8- 4- 0	1,000	400	200	....	200
Tomatoes........	0-20- 0	200	....	200	....	....
Sweet corn........	21- 0- 0	125	125	....	....	....

*The materials used in the experiment are listed here. It should not be inferred that other materials would not prove satisfactory.

†Amount advised for seasons of ample rainfall.

AVAILABLE PHOSPHORUS AND POTASSIUM IN THE SOIL AS SHOWN BY CHEMICAL TESTS

In addition to the soil samples collected in the spring of 1931 (table 6), samples were collected 8 years later in November 1938. The results of chemical tests for available phosphorus and potassium on some of these samples are given in table 21.

By Truog's procedure (6) of shaking the sample in weak acid solution, very large amounts of phosphorus were extracted. Some of the samples showed 300 pounds of phosphorus per 2,000,000 of soil. By pouring an extracting solution through the sample, as commonly done in Morgan's procedure (4), much smaller amounts were obtained. Water extractions were surprising because of the relatively large amount of phosphorus that was found to be water soluble. The procedure was to shake 2 grams of soil in 200 milliliters of water for 30 minutes, filter and refilter until clear, and then determine the extracted phosphorus as in Truog's method. In view of the large amounts of water-soluble phosphorus in this soil, it is not surprising that sweet corn thrived without phosphate fertilizer, and that the yields of the other crops were maintained with applications of only 8 tons of manure per acre.

Tests of soil from growers' fields.—To find out whether growers' soils were at the same high phosphorus level as the experimental plots, six growers' fields at diverse points in the Marietta district were sampled, December 1938. All

TABLE 21.—Tests of soil from plots in phosphate and potash series

Data expressed in terms of pounds per 2,000,000 pounds of soil

Plot	Fertilizer treatment 1931-1938		pH	Available phosphorus			Replaceable potassium	
	Lb. per acre	Formula		Truog's method	Morgan's method	Water soluble	Thornton's method	Morgan's method
Soil sampled November 1938								
Phosphate series								
31	1,000	8- 0- 8	7.1	120	50	50	250	600
32	1,000	8-12- 8	7.2	160	75	60	200	600
34	1,000	8-20- 8	7.2	300	100	100	200	300
Potash series								
11	1,000	8-12- 0	6.5	220	50	70	50	50
10	1,000	8-12- 8	6.7	200	35	60	150	50
19	1,000	8-12-16	6.6	250	50	70	400	200
Manure and phosphate series								
25*	1,000	8- 0- 0	7.2	230	60	70	400	600
26*	1,000	8- 8- 0	7.2	320	75	100	400	500
Soil from the same plots, sampled March 1931								
	Treatment, 1923-1930							
31	625	4-10- 4	7.0	180	....	100	150	....
32	none	....	5.6	90	....	20	75	....
34	625	4-10- 0	7.1	200	....	120	50	....
11	1,250	0-10- 0	6.9	300	....	150	50	....
10	none	....	6.9	140	....	60	50	....
9	1,250	4-10- 0	6.8	300	....	120	75	....
25*	none	....	6.9	220	....	90	600	....
26*	625	4-10- 0	6.9	300	....	150	600	....

*Plots 25 and 26 manured at the rate of 16 tons per acre, 1915 to 1930, 8 tons per acre, 1931 to 1938 inclusive.

were typical Chenango soil. Three of the fields were said to have been heavily fertilized, three lightly fertilized. The analyses are given in table 22. The range of fertility as indicated by these tests was about the same as that found in the experimental plots. The deductions from the experiment should, therefore, be applicable to the Chenango soils of the district.

TABLE 22.—Tests of soil from growers' fields

Pounds per 2,000,000 pounds of soil

Field number	pH	Available phosphorus			Replaceable potassium	
		Truog's method	Morgan's method	Water soluble*	Thornton's method	Morgan's method
1..............	5.2	90	75	87	50	150
2..............	6.0	130	75	85	1,000	400
3..............	5.6	180	75	78	100	150
4..............	6.4	410	150	216	600	600
5..............	7.1	310	150	119	150	150
6..............	7.2	430	150	205	800	600

*Analyses of R. H. Simon of the Soils Division, suspending 5 grams of soil in 500 milliliters of water for 24 hours, then following Zinzadze's procedure (7). This procedure gave somewhat higher values than obtained by the author from shaking the soil in water for 30 minutes.

MODIFICATIONS OF THE RECOMMENDATIONS ON THE BASIS OF THE SOIL TESTS

The recommendations given in table 19 apply to soils testing about 200 pounds of available phosphorus by Truog's method and about 50 pounds of replaceable potassium by Thornton's method. Some of the soils in the Marietta district, as indicated by table 22, are higher in available phosphorus or potassium, and some are lower in available phosphorus. From the data of the experiment, very different recommendations can be deduced for such soils.

Where Truog's test shows less than 120 pounds of phosphorus, as on the check plots in 1931, very much larger proportions of phosphate are required in the fertilizer, except for sweet corn. Moreover, it would probably be advantageous to apply the fertilizer along the row near the plants instead of broadcasting it as in this experiment.

On the other hand, where Truog's test shows more than 200 pounds of phosphorus, the phosphate might be omitted from the fertilizer for several years.

Likewise, on soil with more than 200 pounds of replaceable potassium by Thornton's test, it would seem reasonable to reduce the proportion of potash in the fertilizer. Potash might even be omitted for a few years; during the early years of the experiment, no reduction in yield resulted from omission of potash from the fertilizer. On the other hand, more potash than recommended in table 19 is not likely to be needed on this type of soil.

FURTHER PRACTICAL SUGGESTIONS

Because the low-phosphate fertilizers recommended here are a distinct departure from long-established practice, growers will naturally hesitate to adopt them. From a practical viewpoint, these mixtures are not likely to prove superior to adequate amounts of standard fertilizers, but they are more economical. The obvious conservative procedure is for each grower to have his soil tested and then to try on a small scale the fertilizer recommended.

Which soil test to use.—Quick soil tests have been developed chiefly for soils used for general farming. Not all the tests are well suited for vegetable soils. For example, Morgan's test (4), which is the one most used in Ohio, did not give sensitive tests of this soil. In some cases, soils with 100 pounds of water-soluble phosphorus per 2,000,000 of soil tested only "medium," that is, about 75 pounds, by Morgan's method.

Truog's procedure (6) for estimating available phosphorus, which is not exactly a "quick" test, gave results which corresponded well with the crop responses and with the amounts of phosphorus expected from the previous applications of fertilizer.

The various tests for potassium were not as critically compared, but Thornton's method (5) seemed fairly reliable.

Side dressings.—The benefits from side dressings of nitrogen fertilizer have varied with the seasons. The largest increases have generally been in seasons of highest yields, and the recommendations are for such seasons. Economical applications are still, however, largely a matter of personal judgment of the grower. The practical conclusion from the experiment is that cabbage and sweet corn are more responsive than tomatoes to side applications of nitrogen fertilizer.

Sulfate of ammonia has been used for side dressings in this experiment since 1931, but it should not be inferred from this that it is superior to other nitrogen fertilizers. Sulfate of ammonia has been used because of its relatively low price and because, on well-limed plots in the early years of the work, it proved to be as good as nitrate of soda.

COMPARISON OF THE FERTILIZERS RECOMMENDED WITH THE FERTILITY REMOVED BY THE CROPS

As the fertilizer mixtures recommended here are much lower in phosphorus than those commonly used, the question may be raised as to whether the amounts recommended equal those removed by the crops. Chemical analyses of the crops have not been made, but from numerous analyses reported by other investigators, an estimate can be made of the fertilizer constituents removed in this experiment. As shown in table 23, the amount of phosphoric acid recommended is much larger than the amount removed by the harvested portion of the crop, except with sweet corn.

TABLE 23.—Estimates of the fertilizer nutrients removed by the crops*

All calculations in pounds per acre

	Assumed weight of good crop	Nutrients in the crops			Composition of fertilizer recommended here†		
		Nitrogen	Phosphoric acid	Potash	Nitrogen	Phosphoric acid	Potash
Cabbage, heads	27,000	120	16	114	120	60	120
Tomatoes, fruits	10,000	20	7	32	50	60	120
Cucumbers, fruits	12,000	15	7	13	80	80	80
Sweet corn, ears	8,000	27	5	15	50	none	80
Sweet corn, stover	9,000	27	6	35	....	....	....
Total for four crops	....	209	41	209	300	200	400

*Based on analyses of cabbage and cucumbers as compiled by Winton and Winton in "Structure and Composition of Foods." New York. 1935. Data on tomatoes from MacGillivray and Samson in Amer. Soc. Hort. Sci Proc. 34: 523-526. 1936. Data on sweet corn from unpublished analyses of field corn by V. H. Morris, Department of Agronomy, Ohio Agricultural Experiment Station.

†Not including the nitrogen in side dressings.

The amounts of nitrogen and potash advised are 50 to 100 per cent greater than are likely to be removed by the crops.

With soil in which residual phosphorus and potassium are highly available, such as that in this experiment, it may be questioned whether it is necessary to apply more fertilizer constituents than removed by the crops. The experiment was not planned to test small differences in amounts of fertilizer; hence the recommendations may actually be 50 per cent above the requirements. On the other hand, the practice of applying more fertility than the crops remove is so general in intensive vegetable production that in this respect, the recommendations are in line with general experience.

SPECIAL VALUE OF MANURE ON THIS SOIL

Annual applications of manure have been of particular value in maintaining yields of cucumbers, especially in unfavorable seasons (see table 14). To a lesser degree, the yields of sweet corn have also been higher on manured plots than on any of the fertilized plots. The difference is indicated in table 24.

TABLE 24.—**Yield from fertilizer alone compared with yield from manure with fertilizer**

Average annual yield per acre of plot 6, receiving 1,500 pounds of 8-12-8, and plot 5, receiving 16 tons of manure and 1,000 pounds of 8-8-0 per acre

Crop	Plot 6, no manure	Plot 5, manured	Increase due to manure	
	Lb.	Lb.	Lb.	Per cent
Cucumbers	9,250	11,530	2,280	24.6
Sweet corn	6,628	7,737	1,109	16.7
Tomatoes	9,764	10,300	536	5.5
Cabbage	27,570	27,680	110	.4

There is the possibility that manure supplied some essential nutrient not contained in the commercial fertilizers, but this is a dubious explanation, because in seasons of high yields, there was no indication of any deficiency on the fertilized plots. It seems more logical to assume that the manure applied year after year had sufficient effect on the physical condition of the soil to make moisture or nutrients more available in drouth seasons.

No special study has been made of the structure of the soil, but it has been noted in plowing that the manured soil has been more friable at times. Also, when the soil has been compacted by heavy rain, the manured soil has sometimes been noticeably looser. The organic matter of several plots was determined by Havis and Gourley in 1935 (3). The manured plots had 2.01 to 2.63 per cent, the fertilized plots, 1.44 to 2.11 per cent, of organic matter. On the average, the manured plots were 0.6 per cent higher in organic content. Although this seems a small difference, it appears to have had a perceptible effect on the physical condition of the soil.

As a general conclusion, this soil, cropped year after year, remains in satisfactory physical condition for cabbage and for tomatoes, but more organic matter appears to be essential for maximum crops of cucumbers.

CONCLUSIONS

This is one of very few fertilizer experiments in which the soil has been phosphated to the point where residual phosphorus is ample for the crops. However, in view of the general practice of applying much more phosphorus in fertilizers than is removed by the crops, it is inevitable that other vegetable soils will sooner or later reach this level. Soil tests to indicate this point have not been especially studied, but the results obtained in this experiment suggest that phosphorus tests of water extracts should give at least an indication of whether or not a soil contains enough available phosphorus that further, uneconomical applications of excess phosphate fertilizer can be discontinued.[2]

Another deduction of wide significance can be drawn from the fact that the crops grown in this experiment differed in their capacity to obtain phosphorus from this soil (table 25). This fact has been indicated in other fertilizer experiments and vaguely realized by growers, but has never before been as clearly demonstrated. The obvious practical conclusion is that to ensure maximum yields, a higher level of available phosphorus must be maintained for tomatoes than for cabbage, and a higher level for cabbage than for sweet corn.

[2]The total phosphorus of the soil of this experiment has been reported separately: Bushnell, John. 1941. The phosphorus content of a sandy loam containing sufficient available phosphorus for vegetable crops. Soil Sci. 51: 153-158.

TABLE 25.—Tests for phosphorus on soil near the threshold of the phosphorus level required by the different crops

Plot	Year sampled	Available phosphorus per 2,000,000 pounds of soil		Sufficient for—
		By water extraction	By Truog's method	
31	1931	100	180	Tomatoes
25	1938	70	230	Cucumbers*
31	1938	50	120	Cabbage
32	1931	20	90	Sweet corn

*The data for cucumbers are not as definite as for the other crops because cucumbers did not give maximum yields on unmanured plots. The tests of soil from manured plot 25 are given here to indicate the phosphorus level at which cucumbers did not require phosphate fertilizer with 8 tons of manure per acre.

SUMMARY

This fertilizer experiment, located at the Washington County Truck Crops Experiment Farm, near Marietta, Ohio, has been in progress for 26 years. Four early vegetable crops, tomatoes, cabbage, cucumbers, and sweet corn, have been grown in rotation on the plots.

The soil is Chenango loam and fine sandy loam. It is characterized by a peculiarly low fixing-capacity for phosphorus. Plots fertilized with only 64 pounds of phosphoric acid per acre annually, at the end of 16 years contained sufficient available phosphorus to maintain the yield of tomatoes for 4 years. The soil of these plots tested 100 pounds per acre of water-soluble phosphorus.

The four crops varied widely in their capacity to obtain phosphorus from this soil. For the first 16 years, sweet corn produced good yields without any phosphate fertilizer whatever, but the other crops required some from the outset. An estimate of the relative phosphorus level required by the four crops is given in table 25.

Because of the peculiar availability of phosphorus, relatively little is required in fertilizer. Specific recommendations deduced from the data on yields are summarized in table 19. In general, the amount of nitrogen and potash recommended is higher than commonly applied, and the amount of phosphate much lower.

Eight tons of manure per acre supplied sufficient potassium and very nearly sufficient phosphorus for all crops. Manure alone gave higher yields of cucumbers than any of the fertilizer mixtures tested, particularly in unfavorable seasons. With the other three crops, fertilizers alone gave as high, or nearly as high, yields as any combinations of manure and fertilizer.

Side dressings of sulfate of ammonia increased yields of cabbage and sweet corn, but had little or no effect on the yield of tomatoes and cucumbers.

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